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DEVELOPMENT OF A DUAL DEVICE FOR SOLAR WATER PURIFICATION AND ENERGY CONVERSION

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ABSTRACT

Energy and safe water are indispensable to human wellbeing. However, a population of over a billion in the majority living in the sub-Saharan region are still without access to electricity and safe water. Studies have shown that 80 % of deadly diseases originate from the use of brackish water while electricity challenges pose a hindrance to information access and development.

KEYWORDS: *Provide Electricity and Water, Affects Economic and Industrial Growth*

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INTRODUCTION

With the move by a multitude of space agencies to offer satellite-based internet services to areas out of internet coverage, it is time that research in that area of the world is pitched to the need of the context. The purpose of this paper is to provide a roadmap towards designing a dual-purpose apparatus capable to provide electricity and water to the inhabitants of the region. Both functionalities will run on solar energy aiming to make optimal use of readily available for energy conversion as well as maximum spectrum for water purification.

RESEARCH RATIONALE

About a billion people worldwide have no access to electricity while clean water and this affects economic and industrial growth. Unsafe water and poor sanitation accounts for 80 % of the diseases encountered in developing countries. The strategies of addressing the problems related to the energy crisis using friendly energy sources and ensuring access to clean water for all have been among preoccupations of research institutes, governments, energy agencies, and world health organizations.

On one hand, solar energy, as one of the renewable, clean, and free-of-charge sources of energy, was sought after following the invention of photovoltaic (PV) panels in the 1950s and tops the ranks of renewable energy sources for standalone mode and microgrid (MG) applications. As fixed-tilt have been PVs criticized for not taking full advantage of the sunlight at disposal, systems that track the sun's apparent motion were developed and proved their worth by increasing the energy yield significantly. Further reproach was found against those sun-tracking systems in terms of practicality and implementation, to the point that the old static system remained the favourite in terms of stand-alone-mode energy supply despite their low energy conversion ratio.

On the other hand, while the World Health Organization (WHO) has been intensively collaborating with governments as regards supplying the rural communities with piped water, the latter still contains microorganisms and has major characteristics of the pond grey water. The need for purifying water was imminent and solar energy has been the utmost resort given poor electrification rates in rural areas.

Two major solar technologies emerged so far according to recent research. Firstly, the water purifier unit would be supplied with electric power by a separate PV unit meant to actuate water supply pumps and heat required in the purification process. Secondly, the process of water purification and electric power generation would take place in a single unit of which the main purpose is producing clean water. In both cases, the PV cells have been either used in a classic static mode that leaves a major amount of sunlight wasted or the spectrum of solar energy has been significantly underused. As such, the resulting electric energy and heat yielding is low with respect to the amount of incident sunlight. This appeals for improving the efficiency of existing systems and forms the principal motive of this paper.

INTRODUCTION, BACKGROUND, AND LITERATURE

While over a billion people have no access to electricity and clean water worldwide, 90 % live in rural areas of the sub-Saharan countries of the African continent and India, parts of the earth surrounded by Atlantic and Indian oceans and falling under the intertropical region also called hot belt given the highest intensity of the sun overshadowing the region. In 2018, 115 people still die every minute because of the lack of clean water for drinking, washing, and cooking, while power utilities face the challenge to control the use of unclean energy sources such as fossils and ever skyrocketing energy costs.

Starting with energy problems, optimal exploitation of clean and sustainable energy has been a concern of much research in response to the pressuring energy demands on one hand and the effects of relying on energy sources which are harmful to human beings and the environment on the other hand (World Energy Council, 2016; Bailey, 2011). Solar energy has been regarded as a suitable energy source through photovoltaic (PV) conversion using solar cells.

However, the exploitation of PV devices has been faced with crucial challenges including the production costs that are deemed high, the weather-depending performance (Pachapande & Jalgaon, 2012), the underutilization of the available sunlight (Yilmaz et al., 2015) as well as the effects of heat on the efficiency and lifespan of cells (Domingez et al., 2011; Parida et al., 2011).

Despite the development of dynamic sun-tracking systems as means to improve the collection of the solar irradiance (Kamala & Joseph, 2013; Zhang et al., 2015) and the adoption of cooling technologies (Chow, 2010), some research suggested that, overall, static modules were still the best option for electric power generation (Lapidot et al., 2014).

Concerning the lack of access to clean water, a billion of the world's population still suffer the aftermath of drinking unclean water and poor sanitation that are responsible for 80 % of infectious diseases. The sub-Saharan region of Africa is the most affected with half of the population not accessing the water pressurized piped network, still having no other option than to resort to lakes' and rivers' grey water. In addition water from the piped network needs further treatment as it is often affected by pathogens developing within the piping system. South Africa was one of the African countries where tap water until the recent water crisis struck the Western Cape in particular. There is therefore an imminent need to treat water be it grey or be it from the piped network for the health safety of all the countries' citizens.

Photovoltaic and Water Purification Technologies

Solar PV-water purification systems refer to using solar energy to produce electric power on one hand and/or process unclean water to make it potable. The move to the solar source of energy in producing electricity was embraced following the need to supplement conventional power plants with a clean power source as well as a strive to ensure electricity and potable water supply to populations in remote and rural areas. As said in previous sections, the most affected populations are from the countryside of sub-Saharan Africa as well as India.

Photovoltaics Pivotal in Microgrid in Sub-Saharan Africa

The generation of electric power has been growing at a slow pace concerning the demographic growth of the power users in developing countries, particularly in the sub-Saharan African countries where the population majority lives in off-grid areas. While cities may be intermittently power-supplied, most rural areas live in total darkness. This reality has affected economics and industrial growth and is one of the reasons for the massive immigration of Africans to other continents.

However, that part of Africa confined in a region known as the sunbelt (a region between the tropics) has been blessed with massive solar energy amounting up to 8 kWh/m2, that is eight times the nominal sun radiation supplied to the earth surface every day (Ainah & Folly, 2012). Microgrids (MGs) have been identified as the viable way Africa should go to supply electrify suburban and remote areas given renewable and non-renewable sources endowing the region in the hot belt. The concept of MG can be understood as localized distributed generation (DG) system that combines the functions of electricity generation, storage, control, conversion, monitoring, and management as well as load management tools (Esral, Ahn, Hiskens, Peng, 2011). An MG can operate autonomously or when connected to the national grid in the form of a single electrical power subsystem associated with a small number of distributed energy sources such as solar, wind, hydro, combustion engines, and gas turbines with their associated loads (Lubna, Malabika & Michael, 2013).

Though solar and wind are the most regarded sources of clean energy, PV-based MGs have been the most exploited in Africa. Power utilities have been working towards the integration of MGs into national grids by involving independent power producers (IPP).

MGs have also been regarded as a solution for electrical energy transportation costs to remote areas. From a case study from Kenya, it is reported that MG is more economical than the national grid when it comes to supplying the power to a load located at 9 km. It is therefore important to give more consideration to the development of small-scale localised MGs tailored to the needs of a small village or communities as proved by the study cases of Nigeria, Tanzania, Kenya, Ghana, Uganda, South Africa, etc. (Ainah, Folly, 2012).

However, it is vital to remind the shortcomings of PV-based power generation technologies related to low energy conversion efficiencies relating to the formation of solar or PV modules. Though fixed-tilt have remained highly regarded in terms of power generation ahead of higher efficiency dynamic sun-tracking systems after weighing merits and demerits of each technology, there is an imperative need to consider using wisely the energy readily available and the PVs to their best capacity while supplying the MGs with a steadier amount of incident irradiation.

Water Purification Technologies

Water covers 71 % of the earth's area; 96.5 % is saltwater contained in seas while only 3.5 % contained in lakes and glaciers is freshwater. Furthermore, freshwater is a limited reserve and 69 % of it is in the form of ice. This makes the amount of water available for use to be smaller and smaller as time goes by (Williams, 2014). This is where the idea of

desalinating or distilling seawater emanated in an attempt to supplement the capacity of freshwater reserves. Freshwater has to go through treatment phases before use too due to contaminants. The standard of drinking water as prescribed by the WHO, US Environmental Protection Agency (EPA), European Union (EU), and Bureau of Indian Standards (BIS) (to name but a few) stipulates that the total dissolved solids (TDS) in drinking water should not exceed 600 parts per million (ppm) while water with a TDS exceeding 1,200 ppm may be unacceptable to many (Rajesh, Bharath & Babu Kumar, 2009)

The main water treatment methods that are commercially accepted to treat brackish water are desalination, vapour compression, reverse osmosis, and electrodialysis.

- Desalination: It is a process where brackish or saltwater is evaporated using thermal energy. The vapour steam is collected and condensed to form clean water with a TDS ranging between 10-20 ppm.
- Vapour compression: In this process, distilled water from the boiler is compressed adiabatically and water vapours get superheated then cooled to saturation temperature and condensed at a constant temperature. This process involves mechanical energy.
- Reverse osmosis (RO): In this process, saline water is passed through special membranes which retain salts and other impurities and pass clean water. RO-processed water has a TDS ranging between 500 and 10,000 ppm depending on the membrane technology and several filtration stages.
- Electrodialysis (ED): It is a process where water from a feeder is passed through two membranes connected to the anion and cation and containing an electric field between themselves. Water is separated from salts by an ion-exchange membrane that transports salt ions to another solution. The TDS of the ED-processed water is estimated between 50 and 75 ppm.

Hybrid PV and Water Treatment Technologies

While water treatment processes and electric power generation involve costs to secure the primary energy, solar energy is a gift and its radiation spectrum can cater to both applications at a time. The generation of electricity exploits the visible light only (~25 %) whereas the thermal energy needed for water distillation lies in the far-Infrared region (>50 %) of the total spectrum. The solar spectrum also embeds in its ultraviolet (UV) a tiny portion (5 %) suitable for the disinfection of water through photocatalysis (Fuente, Vivar, Scott & Skryabin, 2010).

Hence, research intensified as regards making optimum use of solar energy by combining both applications in one unit. An ad hoc literature survey was conducted and the works interesting in this research area were summarised.

The first technology consists of water purification using distillation. A PV-run power plant was developed to generate electric power and produce the necessary heat to take water to saturation and distillation thereafter (Serwon, 2016). The role of the PVs in the installation was to generate the power required to drive the pump which in turn helps in piping water all the way to the distillation plant.

The second type is water purification technology using concentrated parabolics through water pipes. Mirrored parabolics fulfil the duty of tracking the sun through the day and concentrate it on a pipe that carries water. The generated heat plays the role of desalinating the water (Mahale & Anwesh, 2016). Sharma et al. (2004) developed a solar-based water distiller comprising triple-staged water reservoirs for vapour condensation. Rajesh et al. (2009) proposed a solar water purifier using flat plate collectors (FPC) exploiting the pasteurization aspect of the

solar spectrum. The focus of the author was solely on water purification and did not make use of visible light to produce electric energy.

The third technology type combines the purification of water and the generation of electricity in a single unit. The operation is such that the water to be purified is mixed with a colour catalyzing agent and posed on a platform made of solar cells and as the colour of water becomes clearer and clearer upon the effect of heat the efficiency of solar cells will increase following the cooling effect resulting from the heat exchange between the water and (Vivar et al., 2012). This hybrid dual-purpose unit does not take full advantage of the incident sunlight which has a negative impact on the electrical conversion and heat exchange efficiencies.

Researcg Gap

The research gap found in existing technologies can be expressed in terms of inefficient use of the amount of readily-available solar energy and the solar spectrum effectively as summarized in Table 1 below.

Table 1: Research Gap

Authors	Main Purpose		Solar Spectrum (%)			Sun-Tracking
	Electrical Power Generation	Water Purification	Ultraviolet (~5 %)	Visible Light (25 %)	Far-Infrared (>50 %)	
Serwon (2016)	x	✓	x	✓	x	x
Mahale & Anwesh (2016)	x	✓	x	x	✓	x
Vivar et al (2012)	✓	✓	✓	x	x	x
Sharma et al (2004)	x	✓	x	x	✓	x
Rajesh et al (2009)	x	✓	x	x	✓	x
Kamanzi & Kahn (2021)	✓	✓	x	✓	✓	✓

AIMS, OBJECTIVES AND METHODS

The aim of this postdoctoral research is to produce a lab-scale hybrid PV-water purifier that will serve as a reference model to meet the energy and safe water needs in the sub-Saharan African countries through the optimum exploitation of solar radiation spectrum and readily available energy within it. The aim is expected to be achieved through the accomplishment of the following objectives:

- Development of a system capable of harvesting the maximum possible incident solar radiation through the daytime.
- Development of a system that will operate rather on solar energy during the major part of the day than relying on batteries on the course of the daytime.
- Development of a system that will make use of solar spectrum at maximum for electric power generation and water purification.

The methodology is designed based on the literature conducted so far and will be organized to achieve the project's aims and objectives and fill gaps identified in existing technologies.

To achieve the maximum use of solar spectrum,

The visible light shall be used for electric power generation through PVs

The far-infrared region containing the thermal energy shall be considered for water heating purposes.

The UV portion represented at 5% shall be used for water purification by photocatalysis. The use of the UV range shall be weighed against its contribution to the system performance and the complexity of the system design may come with.

- To use the solar energy readily available throughout the day, the sun-tracking system will be considered since a moving (dynamic) one has operating issues associated with moving parts especially that it would have to carry a heavy load resulting from the addition of water weight to that of the PVs. The researcher will consider referring to his past work in this regard (Kamanzi & Kahn, 2015; Kamanzi & Kahn, 2016a; Kamanzi & Kahn, 2016b).
- Conduct an up-to-date review of solar energy and water purification systems, their performance, and essential materials.
- Study and conceive the structure capable to fill the gap found in existing PV/water purifier hybrid technologies.
- Establish the specifications of the prospective system.
- Conduct a predictive study of the performance of the prospective system: MATLAB, CAD, and/or Solidworks software packages are the major system simulations tools of focus,
- Build and test and evaluate the system performance: A data acquisition card (DAQ), LabVIEW software package, and power data loggers will be the main tools in line to collect the empirical data.

THE POTENTIAL OF THE PROJECT

The project is in line with global strategies to electrify sub-Saharan African countries through MGs. It is expected to have a notable impact in the field of energy and power, and its outcome will be in the form of novel knowledge and a product. Its uniqueness lies in the aim of exploiting solar energy available from the spectral and amount perspectives to solve energy and clean water problems particularly prevailing in the sub-Saharan African continent.

The project may be of help to get over a billion people out of the darkness. As reported, 1.1 billion people are without electricity whose sub-Saharan countries and India are the most represented in that share (Singer, Denruyter, and Yener, D., 2017). Forecasts also indicate that out of 674 million people expected to be without electricity by 2030, 600 million will still be from sub-Saharan Africa. While the same part of the African continent tops the ranks with regards to suffering from the effects of using unsafe water and unclean energy for cooking purposes, this project is expected to bring a light of hope and serve as a reference with regards to the electrification of households.

Furthermore, with growing interest in getting the whole world connected via satellite broadband, households are to be electrified in the first place.

According to Masunaga (2016), space giants are putting extraordinary efforts into making high-speed broadband connectivity around the globe. Following the request of the French Boeing to put in the low earth orbit (LEO) a constellation of 2,956 satellites (de Selding, 2016), American counterparts filed proposals to the US Federal

Communications Commission (FCC) to launch their constellations of V-band satellites too (Henry, 2017). SpaceX plans to launch a massive constellation of 7,518 satellites, whereas One Web intends to field a constellation of 2,000 satellites in the medium earth orbit (MEO), which will be versatile in services as it will have an extra ability to shuttle between LEO and MEO depending on the type of service required (Henry, 2017). The rationale behind the move is to provide internet to unconnected parts of the world which represent more than a half of the world's population according to figures dated in 2104.

Reports from the International Telecommunications Union (ITU), state that almost half of the world's population lived in the rural regions in 2014 and was majorly unconnected to the networks of telecommunication operators and perhaps to the power utility grids (Masunaga, 2016). Previous efforts of the Chief Executive of Facebook Inc. to bring internet to uncovered areas were hampered after the satellite that was going to provide high-speed services to unconnected areas with a focus on sub-Saharan Africa exploded during its launch (Masunaga, 2016).

Such expansion of space broadband is obviously expected to spark the use of receiving devices in unconnected regions. The solar-energy system the author is proposing will play a pivotal role in getting the disadvantaged countries connected to the world.

CONCLUSIONS AND RECOMMENDATIONS

There is a need to provide substantial and realistic solutions to energy and safe water problems prevailing in the sub-Saharan region. While unsafe water is known to be the cause of 80 % of infectious diseases, electricity issues keep people behind as regards development in terms of education and information. This appeals to pitch research towards the needs of the inhabitants of this part of the world where livings are below the acceptable baseline. A dual apparatus that is able to supply electricity and purify water will be a convenient solution to the problem. Both electricity supply and water purification will rely on solar energy. To make use of the readily-available primary solar energy, the project will make use of a scheme that tracks the sun statically and make sure that off-grid areas have access to electricity for a longer period.

The completion of this project jointly with the underway initiatives in terms of health, energy, and satellite broadband will also have a great impact in terms of having populations in remote areas not only informed but also have them in good health. Once complete, the project will establish channels and connections through which citizens will be able to partake in the governance of their nations.

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